V-BLADE IMPELLER DESIGN FOR A REGENERATIVE TURBINE

FIELD OF THE INVENTION

The invention relates generally to regenerative turbine pumps of the type that are used to pump fuel from a fuel tank to an engine of a motor vehicle. More particularly, the invention pertains to an impeller whose blades are designed to improve substantially the flow of fuel within a regenerative turbine fuel pump, as compared to the type of prior art blade designs typical of the impellers currently in use in the industry.

BACKGROUND OF THE INVENTION

The following background information is provided to assist the reader to understand the environment in which the invention will typically be used. Upon reading this document, the reader will appreciate that the invention may also be applied or adapted to environments other than that described below.

As used in the fuel system of a motor vehicle, a regenerative turbine pump is intended to provide the engine of the vehicle with fuel at relatively high pressure at moderate flow rates. U.S. Pat. Nos. 5,580,213, 5,509,778, 5,393,206, 5,393,203, 5,280,213, 5,273,394, 5,209,630, 5,129,796, 5,013,222 and 4,734,008 are generally representative of the variety of regenerative turbine fuel pumps used in the automotive industry. The teachings of these earlier patents are therefore incorporated into this document by reference.

FIGS. 1–6 illustrate one type of regenerative turbine fuel pump, generally designated 10, along with its associated structure and internal components. This regenerative turbine pump 10 is housed within a tubular metal shell 14, also referred to in the literature as a pump housing. Encased within this metal shell 14 is an electric motor 18. The motor 18 is built around an armature shaft 20, as is well known in the art, and is positioned within the housing 14 so that the shaft 20 can be rotated about a longitudinal center axis 4. Projecting from one end of the housing 14 is a terminal 11. It is through this terminal 11 via a wiring harness (not shown) on the vehicle that electrical energy can be supplied to the electric motor 18.

As best shown in FIGS. 1 and 2, an impeller 12 is mounted to one end of the shaft 20. The impeller 12 is situated between a pair of generally cylindrical plates 22*a* and 22*b*. Between the plates 22*a* and 22*b* there is defined a generally disk-shaped space 24 within which the impeller 12 is designed to rotate. This space 24 is best shown in FIG. 4. An annular groove 23*a* in the inside face of outer plate 22*a* cooperates with an annular groove 23*b* in the outside face of inner plate 22*b* to form an annular pump channel 23. As best shown in FIGS. 3 and 4, the outer plate 22*a* also defines an inlet port 34 that communicates with annular groove 23*a*. Similarly, the inner plate 22*b* defines an outlet port 36 that communicates with annular groove 23*b*.

The fuel tank of the vehicle communicates with the annular pump channel 23 through the inlet port 34 in outer plate 22*a*. This communication occurs through the annular groove 23*a* on the inlet side of impeller 12, as well as through known passageway(s) internal to fuel pump 10. The pump housing 14 has a discharge tube 48 to which the outlet port 36 is connected via other known passageway(s) within the fuel pump 10. Through outlet port 36, discharge port 48 communicates with the annular pump channel 23 on the outlet side of impeller 12, i.e., through annular groove 23*b*. It is from this discharge tube 48 that pressurized fuel is

discharged from and delivered by the fuel pump 10 for use by the engine of the vehicle.

The impeller 12 serves as the rotary pumping element for the regenerative turbine pump 10. As shown in FIGS. 1–5, the impeller 12 basically takes the form of a disk having a hub 26 whose axis of rotation is centered on center axis 4. The hub 26 defines an aperture 28 at its center. The aperture 28 is notched, to accommodate the like-shaped shaft 20 of motor 18. The notched aperture 28 allows the shaft 20 to drive the impeller 12 when the electrical motor 18 is activated.

The impeller 12 has a plurality of fan blades 30 that project radially outward from the hub 26. Also referred to as vanes, the fan blades 30 are generally spaced from each other uniformly. As best shown in FIGS. 4–6, each of the vanes 30 is V-shaped. Radiating from the periphery of hub 26, the vanes 30 are situated in between and adjacent to the annular grooves 23*a* and 23*b* in outer and inner plates 22*a* and 22*b*, respectively. In other words, the vanes 30 are positioned directly within the annular pump channel 23 of the regenerative turbine pump 10.

FIGS. 5 and 6 illustrate the structure of the vanes 30. Each V-shaped blade 30 has a pair of fin members 30*a* and 30*b*, each having a generally rectangular cross-section. The base of each fin member emanates from the hub 26. Each fin member 30*a* and 30*b* lies at angle of approximately 45° with respect to a plane of intersection 5 that bisects impeller 12 longitudinally. This plane appears as a line in FIG. 6, as two fan blades 30 of impeller 12 are viewed therein from the top. The inner sidewalls 31*a* and 31*b* of fin members 30*a* and 30*b* are formed together along the plane 5 during the injection molding process that is used to manufacture the impeller 12. From their adjoined inner sidewalls, the fin members of each vane 30 diverge away from each other. These adjoined fin members 30*a* and 30*b* together form upstream and downstream faces. Facing the direction of rotation 6, the upstream face of each vane 30 is generally concave, exhibiting an angle of approximately 90°. The downstream face is convex, exhibiting a similar angle on the back side of vane 30. Each vane 30 also has two generally flat outer sidewalls 32*a* and 32*b*. Fin member 30*a* has outer sidewall 32*a* and fin member 30*b* has outer sidewall 32*b*.

FIG. 5 best illustrates how the vane(s) 30 are oriented with respect to, and are moved within, the annular pump channel 23. FIG. 5 shows the annular groove 23*a* in the inside face of outer plate 22*a*. The annular groove 23*b* in the outside face of inner plate 22*b* is best shown in FIG. 2. Outer sidewall 32*a* lies directly adjacent to annular groove 23*a*, and outer sidewall 32*b* lies adjacent to annular groove 23*b*. The vanes 30 of impeller 12 thus lie within the annular pump channel 23 that is defined by annular grooves 23*a* and 23*b*. In addition, as shown in FIG. 5, each vane 30 can be considered as having an entrance portion 37 and an exit portion 38. The entrance portion 37 extends generally from the hub 26 to midpoint of annular pump channel 23. Shaded in FIG. 5, the exit portion 38 extends from the midpoint to the distal end of the vane. Each vane 30 thus extends radially outward from the hub 26.

The regenerative turbine fuel pump 10 operates as follows. When electricity is supplied via terminal 11 to the electric motor 18, the armature shaft 20 immediately begins to rotate. The rotation of shaft 20, in turn, causes the impeller 12 to rotate within the disk-shaped space 24 between the inner and outer plates 22*a* and 22*b*. Fuel from the fuel tank is sucked into the inlet port 34 and flows into the annular groove 23*a*, and thus into the annular pump channel 23.

The rotation of the impeller **12** imparts both a centrifugal and a tangential force on the fuel. As the impeller **12** rotates, its V-shaped vanes **30**, in combination with annular grooves **23***a* and **23***b* on either side, cause the fuel to whirl about the annular pump channel **23** in a toroidal flow path, as is best shown in FIG. **5**. More specifically, the centrifugal force moves the fuel with velocity in the radial direction with respect to hub **26**. This causes the fuel to traverse the length of each blade **30**, i.e., fuel enters the base of each vane flowing from the root along entrance portion **37** and exit portion **38** and exits the tip. As it enters annular pump channel **23**, the fuel is redirected by the walls of the channel **23**, causing it to circle or spiral back towards the root of the trailing vane. This cycle is repeated continuously as the impeller **12** rotates.

As is known in the art, this regenerative cycle of exiting the tip of the leading blade **30** and entering the base of the trailing blade **30** occurs many times as the fuel is conveyed through the annular pump channel **23** by the vanes **30** on the periphery of the rotating impeller **12**. Each regenerative cycle thus imparts a generally circular (radial) velocity to the fuel.

The combined geometry of the annular pump channel **23** and the vanes **30** of the impeller ultimately cause the fuel to flow within, and in a direction that is tangential to, the annular pump channel **23**. The collective action of the blades **30** thus imparts a tangential velocity to the fuel. The combination of the circulatory and tangential velocities causes the fuel to flow in a toroidal pattern within the annular pump channel **23**. The tangential velocity with which the fuel flows in the direction of rotation **6** is generally characterized by $V_t=R\overline{\omega}$, where R is the radius or distance from the center of hub **26** and $\overline{\omega}$ is the angular velocity (i.e., the rate of change of angular displacement with respect to time).

As fuel exits the tip of each vane and enters the annular pump channel **23**, angular or tangential momentum is transferred to the fuel. This gives rise to the tangential velocity with which the fuel is carried toward the outlet port **36** defined in inner plate **22***b*. From the outlet side of impeller **12** (i.e., through annular groove **23***b*), the flowing fuel then exits through the outlet port **36**. The fuel continues flowing through the internal passageway(s) of the pump housing **14** and exits the fuel pump **10** through discharge port **48**. In this known manner, fuel at relatively high pressure is provided to the engine of the motor vehicle at an appropriate rate of flow.

With its V-shaped vanes **30**, the impeller **12** is, of course, the rotary pumping element that is responsible for increasing the momentum of the fuel with each regenerative cycle. The efficiency of the turbine fuel pump **10**, however, is limited by the non-streamlined design of the vanes. The current design of the vanes causes some of the energy to be lost from the flow of fuel. In particular, the impeller **12** has at least three design limitations that lessen the angular momentum being imparted to the fuel as it flows within the annular pump channel **23**.

The first design limitation involves the downstream face of each vane **30**. Specifically, some energy in the stream of fuel is lost behind each blade **30** due to the separation of the fluid stream and the low pressure area resulting therefrom. The area where this energy loss occurs is depicted at L_1 in FIG. **6**, generally just behind the trailing corner **33** of each fin member.

The second design limitation involves the upstream face of the vanes **30**. In particular, the flow of fuel loses energy at the point at which the fuel impacts the leading corners of each fan blade **30**. The area where this energy loss occurs is depicted at L_2 in FIG. **6**. The combined losses due to separation and low pressure behind each blade **30** and impact of the fuel on the forward facing corners of each blade **30** serve not only to decrease the rate at which the fuel flows but also the pressure at which the fuel is provided to the engine.

The third design limitation involves the configuration of the entrance and exit portions **37** and **38** of the fan blades **30**. The entrance and exit portions of each vane, as currently configured, direct the fuel to flow in the radial direction only, with respect to hub **26**, from the root of the vane to the tip. Consequently, the angular momentum of the fuel as it flows within the annular pump channel **23** would be increased if the fuel were to exit from the exit portion **38** in a direction that is more tangential with respect to the annular pump channel **23**. In addition, because the vanes extend radially outward from hub **26**, the fuel as it enters the root of each vane **30** loses energy at the point at which it impacts the entrance portion **37**.

OBJECTIVES OF THE INVENTION

It is, therefore, an objective of the invention to provide a novel impeller whose V-shaped vanes improve substantially the flow of fuel within a regenerative turbine fuel pump.

A related objective is to provide an impeller whose specially configured dual-angled V-shaped vanes impart greater momentum to the fuel flowing within the annular pump channel of a regenerative turbine fuel pump.

Another related objective is to provide an impeller whose specially configured curve-surfaced or "hooked" V-shaped vanes impart greater momentum to the fuel flowing within the annular pump channel of a regenerative turbine fuel pump.

A further objective is to provide an impeller for a regenerative turbine pump that minimizes energy losses associated with the circulatory flow of the fuel impacting against the forward faces of the vanes as well as energy losses caused by the separation of the fuel stream behind the vanes.

A related objective is to provide an impeller whose vanes are designed to reduce the amount of energy lost from the fuel stream by minimizing the separation of the fuel stream behind each vane and the development of a low pressure area thereat.

Another related objective is to provide an impeller whose vanes are designed to reduce the amount of energy lost from the fuel stream by lessening the force with which the circulating fuel stream impacts the forward faces and corners of each vane.

In addition to the objectives and advantages listed above, various other objectives and advantages of the invention will become more readily apparent to persons skilled in the relevant art from a reading of the detailed description section of this document. The other objectives and advantages will become particularly apparent when the detailed description is considered along with the accompanying drawings and claims.

SUMMARY OF THE INVENTION

The foregoing objectives and advantages are attained by a novel impeller for a regenerative turbine fuel pump. The fuel pump for which the impeller is designed should have an electrical motor and a shaft rotatable thereby about a center axis. In a generic manifestation, the novel impeller comprises a hub, an outer ring and a plurality of innovative

V-shaped vanes. At its center, the hub defines an aperture into which the shaft of the fuel pump is securable to allow the hub to rotate with the shaft about the center axis. The outer ring is concentric to the hub. The vanes extend from an outer surface of the hub to an inner surface of the outer ring. Each vane comprises an entrance portion that extends from the outer surface of the hub and an exit portion that extends from the entrance portion to the inner surface of the outer ring. Each vane has a V-shape of a prespecified angle centered relative to a plane normal to the center axis. Each vane is also at least partially non-linear on at least one of an upstream face and downstream face of the vane from the entrance portion thereof through the exit portion thereof. The entrance and exit portions of each vane each have a pair of outer sidewalls. Each outer sidewall of each entrance portion is chamfered along a trailing corner thereof. The chamfer is made at a predetermined angle relative to the aforementioned plane.

In a first presently preferred embodiment, the entrance portion of each V-shaped vane extends linearly outward from the outer surface of the hub. In addition, the exit portion of each vane is inclined forward of the entrance portion. In particular, the exit portion is inclined forward so that it is oriented toward the inner surface of the outer ring at an exit angle with respect to a direction of rotation of the impeller. The exit angle preferably lies within a range of 15° to 50°.

In a second presently preferred embodiment, each V-shaped vane is curved from the outer surface of the hub to the inner surface of the outer ring. More specifically, the entrance portion is oriented so that it draws away from the outer surface at an entrance angle with respect to a direction of rotation of the impeller. The exit portion is oriented so that it advances toward the inner surface at an exit angle with respect to the direction of rotation. The entrance angle preferably lies within a range of 5° to 30°, and the exit angle preferably lies within a range of 15° to 50°.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional side view of a conventional regenerative turbine fuel pump, showing an impeller attached to the end of a shaft of an electric motor.

FIG. 2 is an enlarged view of the lower end of the regenerative turbine fuel pump shown in FIG. 1, showing more clearly the impeller attached to the end of the shaft.

FIG. 3 is a sectional view taken generally along the plane indicated by lines A—A in FIG. 2, showing the vanes of the impeller through an inlet port defined in an outlet plate.

FIG. 4 is an enlarged sectional view taken generally along the perimeter indicated by lines B—B in FIG. 3, showing the relationship between the V-shaped vanes of a prior art impeller and the inlet and outlet ports defined within the outer and inner plates, respectively, of the fuel pump.

FIG. 5 is a partial three-dimensional view of the outer plate and the prior art impeller, showing how the V-shaped vanes are oriented with respect to the annular pump channel.

FIG. 6 is an enlarged top view of two adjacent V-shaped vanes of the prior art impeller, showing how the fuel stream flows into and then around the fin members of the leading vane.

FIG. 7 is a side view of a closed-vane impeller showing the novel dual-angled V-shaped vanes according to a first embodiment of the invention.

FIG. 8 is a sectional view of the impeller shown in FIG. 7 taken generally along the plane indicated by lines A—A.

FIG. 9 is an enlarged view of a section of the impeller, indicated by circle B in FIG. 7, showing the exit and entrance portions of several of the dual-angled V-shaped vanes.

FIG. 10 is an enlarged, partial sectional view taken generally along the plane indicated by lines C—C in FIG. 7, showing the entrance portion of several of the V-shaped vanes.

FIG. 11 is an enlarged, partial sectional view taken generally along the plane indicated by lines D—D in FIG. 7, showing various partial portions of several V-shaped vanes.

FIG. 12 is an enlarged top sectional view of the entrance portion of two adjacent vanes of the impeller shown in FIG. 7, showing the chamfer on the trailing corners of the entrance portion of each vane and how the fuel flows therearound.

FIG. 13 is an enlarged view of a section of a closed-vane impeller showing the novel curved-surfaced or "hooked" V-shaped vanes according to a second embodiment of the invention.

FIG. 14 is a sectional view taken generally along the plane indicated by lines A—A in FIG. 13.

DETAILED DESCRIPTION OF THE INVENTION

Before describing the invention in detail, the reader is advised that, for the sake of clarity and understanding, identical components having identical functions have been marked where possible with the same reference numerals in each of the Figures provided in this document.

FIGS. 7–14 illustrate the essential details of the invention, namely, a novel impeller **212** for a regenerative turbine fuel pump **10**. The regenerative turbine pump **10** for which the impeller **212** is designed will generally include an electric motor **18**, a shaft **20**, a generally cylindrical outer plate **22*a*** and a generally cylindrical inner plate **22*b***. FIGS. **1** and **2** show that the shaft **20** is rotatable by the motor **18** about a center axis **4** in a forward direction **6**. They also show that the outer plate **22*a*** has an inside face that defines a first annular groove **23*a***. Similarly, the inner plate **22*b*** has an outside face that defines a second annular groove **23*b***.

The first and second annular grooves **23*a*** and **23*b*** cooperate to form an annular pump channel **23** at a periphery of a disk-shaped space **24** defined between the inner and outer plates **22*b*** and **22*a***, as best shown in FIGS. **3** and **4**. Outer plate **22*a*** further defines an inlet port **34** that communicates with the first annular groove **23*a***. Similarly, inner plate **22*b*** defines an outlet port **36** that communicates with second annular groove **23*b***.

Two presently preferred embodiments of the invention, namely, the dual-angled and curved-surfaced embodiments, are shown in FIGS. **7–12** and **13–14**, respectively. In both embodiments, the impeller **212** comprises a hub **26**, an outer ring **40** and a plurality of innovative V-shaped vanes **60/160**, as best shown in FIGS. **9** and **13**, respectively. The hub **26**, the outer ring **40** and the V-shaped vanes **60/160** can be formed on a single part by use of an injection molding process. Several injection molding processes are well known in the industry. The molding process used to make the prior art impeller **12** is one such known process, but it has heretofore not been used to make an impeller **212** having the novel features disclosed in this document.

The hub **26** has a cylindrical outer surface **27**. The hub **26** also defines an aperture **28** into which the shaft **20** can be secured. This allows the impeller **212** to rotate with shaft **20**

about the center axis 4 in the forward direction 6, when motor 18 is supplied with electricity via the terminal 11 that protrudes from the pump housing 14. Concentric to hub 26, the outer ring 40 has a cylindrical inner surface 41.

During the injection molding process, the vanes 60/160 are formed on the hub 26 so that they extend from the outer surface 27 of hub 26 to the inner surface 41 of outer ring 40. In terms of operation, each V-shaped vane 60/160 can be considered to have an entrance portion 61/161 and an exit portion 62/162, as best shown in FIGS. 9 and 13. In particular, the entrance portion 61/161 of each vane extends from the outer surface 27 of hub 26, and the exit portion 62/162 extends from the entrance portion 61/161 to the inner surface 41 of outer ring 40.

Each vane 60/160 has a V-shape of a prespecified angle α centered relative to a plane 5 normal to the center axis 4. Although only shown for the dual-angled embodiment in FIGS. 10 and 11, the prespecified angle α also applies to the curved-surfaced embodiment. For the upstream face of each vane, the prespecified angle α_U lies within a range of 50° and 130°, as shown in FIG. 11. Preferably, α_U is 90°. For the downstream face, as best shown in FIG. 10, the prespecified angle α_D ideally lies within a range of 80° and 86°, with 82.3° being the preferred value. Stated in another way, the fin members of each vane 60/160 diverge from each other on their upstream and downstream faces by angles α_U and α_D, respectively.

Still describing each embodiment generically, each vane 60/160 is also at least partially non-linear on either of its upstream face or downstream face or both from the entrance portion 61/161 through the exit portion 62/162. In addition, the entrance and exit portions of each vane 60/160 each have a pair of outer sidewalls. More specifically, the outer sidewalls 61*a* and 61*b* of the entrance portions 61 for the dual-angled embodiment are best shown in FIGS. 9, 10 and 12. The outer sidewalls 62*a* and 62*b* of the exit portions 62 are best shown in FIGS. 9 and 11. Similarly, the outer sidewalls 161*a* and 161*b* of the entrance portions 161 for the curved-surfaced embodiment are best shown in FIG. 13. The outer sidewalls 162*a* and 162*b* of the exit portions 162 are shown in FIGS. 13 and 14. As described in further detail below, along their respective trailing corners, the outer sidewalls of at least the entrance portions 61/161 of the vanes 60/160 are chamfered at a predetermined angle β relative to plane 5.

Secured to the shaft 20 of motor 18, the impeller 212 is designed to lie within the disk-shaped space 24, with the vanes 60/160 lying between the first and second annular grooves 23*a* and 23*b* in annular pump channel 23. This is best suggested by FIG. 5, as viewed in conjunction with FIGS. 7–12 and 13–14. Specifically, the outer sidewalls 61*a* and 62*a* (161*a* and 162*a*) of each vane 60 (160) will lie adjacent to the first annular groove 23*a*. Similarly, the second outer sidewalls 61*b* and 62*b* (161*b* and 162*b*) of each vane 60 (160) will lie adjacent to the second annular groove 23*b*. Rotation of the impeller 212 moves the V-shaped vanes 60/160 along the annular pump channel 23 in the forward direction 6, shown in FIGS. 7, 9–11 and 13–14. The movement of the vanes 60/160 causes fuel from the fuel tank to be sucked into the inlet port 34 and flow into the annular groove 23*a*, and thus into the annular pump channel 23 and eventually out of the outlet port 36 in inner plate 22*b*.

As can be understood in the context of this invention in light of the information provided in background, the movement of the innovative vanes 60/160 imparts momentum to the fuel stream. The vanes 60/160 cause the fuel to whirl about the annular pump channel 23 in a toroidal flow path. This, of course, is characteristic of the regenerative cycle in which the fuel enters the base of each vane 60/160 then flows from the root along entrance portion 61/161 and exit portion 62/162. As it leaves the tip of the exit portion 62/162 and impacts the walls of annular pump channel 23, the fuel is redirected by the walls of the channel 23 in a circular or spiral path back towards the entrance portion 61/161 of the trailing vane 60/160. This cycle is repeated continuously as the impeller 212 rotates, causing the V-shaped vanes 60/160 to impart momentum to the fuel.

Referring now to the first presently preferred embodiment of the invention shown in FIGS. 7–12, the dual-angled V-shaped vanes 60 of impeller 212 are distinctly configured, as compared to the vanes 30 of the prior art impeller 12. Unique to the dual-angled vanes 60, the entrance and exit portions 61 and 62 of each vane are angled with respect to each other. More accurately, the entrance portion 61 of each vane 60 extends linearly outward from the outer surface 27 of hub 26. As best shown in FIG. 9, the entrance portion 61 preferably extends radially outward with respect to the center axis 4 of hub 26. In addition, the exit portion 62 of each vane 60 extends linearly from the entrance portion 61 to the inner surface 41 of outer ring 40. In particular, the exit portion 62 is inclined forward of the entrance portion 61 so as to advance toward the inner surface 41 of outer ring 40 at an exit angle θ. Inclined with respect to the direction of rotation 6 of the impeller, the exit angle θ lies within a range of 15° to 50°. This is best shown in FIG. 9. Within that range of angles, the tangential velocity of the fuel as it exits the tip of the exit portion 62 is generally characterized by $V_t = R_0 \overline{\omega} + V_r$ sine θ.

Novelty also resides in the trailing corners of the outer sidewalls of the vanes 60. During the manufacturing process, the trailing corners of at least the entrance portion 61 of each vane 60 are chamfered. More specifically, the trailing corners 63*a* and 63*b* of each entrance portion 61 are chamfered at a predetermined angle β relative to each other, as best shown in FIGS. 10 and 12. This predetermined angle β lies within a range of 30° to 90°. Preferably, the predetermined angle β is 60°. As measured relative to plane 5, however, the predetermined angle lies within a range of 15° to 45°, with 30° being the preferred valve relative to plane 5.

The trailing corners 64*a* and 64*b* of each exit portion 62 of each vane 60 may also be chamfered at the predetermined angle β. This is best illustrated in FIGS. 9 and 11.

The predetermined angle β would ideally be equal to the angle at which the fuel stream approaches each of the outer sidewalls, as the vanes 60 move along the annular pump channel 23. The preferred angle of 60° for the chamfer of the trailing corners has been chosen to match, as closely as possible, the angle at which the fuel enters the base of the outer sidewall of each vane 60. The chamfering of each trailing corner gives each outer sidewall a narrower profile. This minimizes the separation of the fluid fuel stream that occurs behind each vane 60. Consequently, low pressure is less likely to develop behind the fin members of each vane 60. This factor alone means that the stream of fuel loses less energy during each regenerative cycle, as compared to the prior art vanes 30.

Due to the chamfered trailing corners, the narrower profile of each outer sidewall also reduces the surface area against which the fuel stream impacts. This factor also means less energy lost during the regenerative cycle. The chamfers thus yield not only less separation and turbulence of the fuel

stream behind each fin member but also a reduction in the force with which the fuel stream impacts the leading corners of each vane. As compared to prior art impellers, the impeller **212** with its chamfered vanes **60** causes the fuel stream to lose significantly less energy during operation of the turbine fuel pump **10**.

If it is necessary to further reduce the cost of manufacturing the impeller **212**, the trailing corners **64***a* and **64***b* of the exit portions **62** need not be chamfered. Merely chamfering the trailing corners **63***a* and **63***b* of the entrance portions **61**, at the base of the vanes **60**, will still yield suitably improved results. That is because the trailing corners **63***a* and **63***b* along the edge of each fin member are where the fuel stream enters each V-shaped vane **60** during the regenerative cycle, as the impeller rotates.

Referring now to the second presently preferred embodiment of the invention shown in FIGS. **13–14**, the impeller **212** may be equipped with hooked or curved-surfaced V-shaped vanes **160**. Unique to this embodiment, the entrance and exit portions **161** and **162** of the vanes **160** are each curved. More specifically, the entrance portion **161** draws away from the outer surface **27** of hub **26** at an entrance angle ϕ with respect to the direction of rotation **6** of the impeller. Similarly, the exit portion advances towards the inner surface **41** of outer ring **40** at an exit angle ϕ with respect to the direction of rotation **6**.

FIG. **13** best illustrates the entrance and exit angles of the vanes **160**. The entrance angle ϕ preferably lies within a range of 50 to 30°, and the exit angle ϕ preferably lies within a range of 15° to 50°. The center portion of each vane **160** is the point at which the entrance and exit portions **161** and **162** meet. A tangent drawn at the center portion of each curved vane **160** is preferably normal to the direction of rotation **6**.

The entrance and exit angles and the overall curvature of the V-shaped vanes **160** serve to improve the velocity of the fuel, both radially and tangentially, within the annular pump channel **23**. Specifically, the entrance angle ϕ serves to reduce the force with which the fuel impacts the root of the vane **160**, further minimizing the amount of energy lost from the fuel stream. This reduction in force is generally proportional to the cosine of the entrance angle (i.e., $F \approx m(V_{Blade} \times \text{cosine}\ \phi) - V_{Fluid}$). It also serves to increase the circulatory (radial) velocity of the fuel. As with the first embodiment, the exit angle ϕ serves to increase the tangential velocity with which the fuel exits the tip of the vane **160**. The exit angle ϕ directs a component of the circulatory velocity towards the tangential direction ($V_{Tan} = V_{Tip} + V_C$ sine ϕ). This increases the angular momentum of the fuel as it flows from the tip of each curved vane **160** into the annular pump channel **23**.

As with the dual-angled blades **60** of the first embodiment, the entrance portions **161** of the curved-surfaced vanes **160** are preferably chamfered. In particular, the trailing corners **163***a* and **163***b* of each entrance portion **161** are chamfered at the predetermined angle β relative to each other, as shown in part in FIG. **13**. The trailing corners **164***a* and **164***b* of each exit portion **162** may also be chamfered at the predetermined angle β. This is best illustrated in FIGS. **13** and **14**.

Three impellers incorporating the curved-surfaced V-shaped vanes **160** have been tested. Each impeller selected for the test had a width of 3 millimeters (mm) and an outer diameter (i.e., the distance from the center axis **4** to the inner surface **41** of outer ring **40**) of 32.75 mm. One impeller had an exit angle of 26°. Another impeller had an

exit angle equal to 45°. The third impeller had an exit angle of 45° and trailing corners chamfered at a predetermined angle β of 60°. The predicted and actual values of flow rate and hydraulic efficiency for each of these impellers are listed in the following table. The values were based on the impeller operating at 5000 rotations per minute (rpm) at a pressure of 380 kilopascals (kPa) at the outlet port **36** and 0 kPa at the inlet port **34**.

Impeller: Width = 3 mm.; Outer Diameter = 32.75 mm.; RPM = 5000; Outlet = 380 kPa; Inlet = 0 kPa

Exit Angle (Degrees)	Flow Rate-Predicted (Grams/Second)	Flow Rate-Actual (Grams/Second)	Hydraulic Efficiency (Percent)
26°	21.5	22.7	44.6%
45°	23.9	25.0	50.1%
45°/60°	28.0		52.8%

Expressed in terms of percentage, the hydraulic efficiency is the quotient of the product of the mass flow of the fuel (flow rate) and the pressure at the outlet port **36** (380 kPa) divided by the product of the torque and rotational speed of the shaft **20**. It is the ratio of the output energy (energy of the fuel stream at the outlet port **36**) and the input energy (the mechanical energy of the rotating shaft **20**).

In both of its embodiments, the novel impeller **212** improves substantially upon the prior art impeller **12** discussed in background. It improves the overall mechanical efficiency of the high pressure section of the turbine fuel pump **10**. In doing so, however, the impeller **212** still retains a geometry that allows it to be manufactured by conventional injection molding techniques at a relatively low cost. More specifically, the non-linear configuration of each vane **60/160** imparts greater momentum to the fuel, as compared to the design of the prior art vanes, at any given rotational speed of the impeller. In addition, the geometry of the chamfers on the trailing corners of each vane is achieved without adversely affecting either the thickness of the root of each vane or the helical angle of retraction characteristic of the injection molding process used to make the impeller. In other words, the impeller is provided with streamlined vanes in such a way as to not compromise or complicate the injection molding process used to make it.

Testing and analysis has revealed that a regenerative turbine fuel pump equipped with the impeller **212** provides 25% higher head capability not only when the pump **10** is shutoff but also throughout the range of flow with no increase in torque. Moreover, the performance of a regenerative turbine pump **10** equipped with the impeller **212** is greatly improved versus impellers having the prior art V-shaped vanes.

The presently preferred embodiments for carrying out the invention have been set forth in detail according to the Patent Act. Persons of ordinary skill in the art to which this invention pertains may nevertheless recognize various alternative ways of practicing the invention without departing from the spirit and scope of the following claims. Persons who possess such skill will also recognize that the foregoing description is merely illustrative and not intended to limit any of the ensuing claims to any particular narrow interpretation.

Accordingly, to promote the progress of science and the useful arts, we secure for ourselves by Letters Patent exclusive rights to all subject matter embraced by the following claims for the time prescribed by the Patent Act.